The Chesapeake Bay Land Change Model
Executive Summary

Introduction

The Chesapeake Bay's water quality is highly dependent on the state of the surrounding land mass. Over the past 30 years, the population of the Chesapeake Bay watershed has increased by over 4 million people. County population projections show that the population will increase by an additional 2.5 million through the year 2030. The Chesapeake's land-to-water ratio (14:1) is the largest of any coastal body of water in the world. The Chesapeake Bay's water quality in large part reflects the state of the surrounding land mass. Currently, over 90% of the Bay and its tidal waters are listed by the U.S. Environmental Protection Agency as impaired due to low dissolved oxygen levels and/or poor water clarity related to nutrient and sediment pollution. Over the past four centuries, land use has undergone massive changes with forests and shorelines making way for agriculture, silviculture, suburbanization, and urbanization. If current development trends continue, urban land in the Chesapeake Bay watershed will increase by 60% through the year 2030 (Boesch and Greer, 2003).

A major challenge facing water resource managers today is how to maintain progress restoring the Chesapeake Bay in the face of continued population and urban growth. The Chesapeake Bay Land Change Model (CBLCM) was developed to help address this management challenge. In conjunction with the Chesapeake Bay Watershed Model (CBWM), Airshed Model, and Water Quality Model, the CBLCM can be used to assess potential future changes in nutrient and sediment loads to the Bay.

Scale

To meet the data requirements of the CBWM, the CBLCM must be capable of forecasting change at the watershed modeling segment scale. The latest version of the CBWM is called "Phase 5." This version includes over 2000 modeling segments (e.g., polygons) within the Bay watershed and intersecting counties. These segments were created based on an intersection of county boundaries, major topographic divides, and a 1:250,000 scale river reach drainage area network. Because the modeling segments are nested within counties, all data generated at the modeling segment scale can also be provided at the county scale for local review and comment.

Components

In support of the CBP management concerns, researchers from the US Geological Survey, US Environmental Protection Agency, Shippensburg University, and a private consultant developed the CBLCM which combines the strengths of a ***g**rowth **a**llocation **m**odel*, *GAMe* (Reilly, 2003), with those of a cellular automata model, *SLEUTH* (***s**lope, **l**and use, **e**xcluded land, **u**rban extent, **t**ransportation, and **h**illshade*) (Clarke, et al., 1997; Jantz et al., 2003). The GAMe model projects future urban area at the watershed modeling segment scale by fitting total housing unit trends over the 1990's to a Gompertz (exponential "S"-shaped) curve which is then used to extrapolate housing trends to the year 2030. County population projections[1] converted to County scale estimates of total housing demand are used to constrain the modeling segment scale forecasts generated using the Gompertz Curve. After the model segment scale forecasts of housing demand are adjusted to match the County scale housing demand totals, they are converted to an estimate of future urban area using segment specific ratios of urban land cover area to total housing units.

The proportions of urban growth occurring on farmland, forest land, sewer, septic, and within existing urban boundaries are determined uniquely for each watershed modeling segment using the SLEUTH urban growth model, a stochastic cellular automata model customized for application in the Chesapeake Bay watershed by Goetz and Jantz (2006). SLEUTH extrapolates historic rates and patterns of urban growth into the future using satellite derived imagery of 1990 and 2000 impervious cover. SLEUTH was calibrated separately in fifteen different County-clusters in the Bay watershed. Counties were clustered together based on shared characteristics of urban growth, commuting patterns, and state and ecoregion boundaries. SLEUTH uses a Monte Carlo method to generate multiple simulations of future growth which are combined to create a probability map of future urban development. The output from SLEUTH is a 30m-resolution probability raster dataset that indicates the probability of urban growth in the year 2030 with values ranging from 0 to 100 percent.

The patterns of probable growth may vary for each cluster of counties based on the coefficients used to calibrate SLEUTH in each cluster. The patterns and levels of probable urban growth may also vary within a county based on local factors of attraction and repulsion. These factors are represented in a 30m-resolution raster dataset referred to as an "exclusion layer". Local areas "off limits" to development may include public lands, conservation easements, rurally zoned lands, steep slopes (greater than 21% grade), emergent wetlands, and open water. For the Bay watershed, an exclusion layer was created in a GIS using information on public and protected lands, generalized zoning, and land cover. Values greater than 50 are relatively repulsive to growth with 100 being completely excluded. Values less than 50 are relatively attractive to growth (e.g., areas zoned for moderate or high density growth). The mid-point, 50, is neutral.

The probability output from SLEUTH is overlaid onto a raster land cover dataset to determine the relative proportions of land cover classes and sewer areas impacted by future growth. For example, if a cell with a fifty-percent probability of becoming developed by 2030 overlays a forest cell in the land cover map, then fifty-percent of that quarter-acre cell is considered forest loss. For each modeling segment, the total acreage of all land cover classes converted to urban growth are summed and divided by the total amount of urban growth acreage forecasted in the modeling segment. This process generates relative

[1] For the Bay watershed, county population projections out to the years 2010, 2020, and 2030 are supplied by state and regional government agencies.

proportions of future growth by land cover class for each modeling segment. Multiplying these proportions by the acreage of forecasted growth (generated by GAMe) determines how much acreage to subtract or add in future years to the Phase 5 watershed model 2002 baseline land use classes.

The CBLCM also includes a Sewer Model to estimate the population on sewer and septic in the years 2000 and 2030. Where local data was not available, a population density raster dataset derived from year 2000 Census Block Group data and detailed road vector files was used to represent probable sewered areas in the year 2000. This approach captures 81% of Maryland's mapped residential sewered areas based on a one-to-one cell comparison. This approach also compares favorably with survey data in Virginia representing households with sewer service in the 2001 to 2005 time period.

Modeled sewered areas in the year 2000 were expanded along existing roads by 300m to 2000m to represent possible expansion of the sewer network through the year 2030. Forecasted population values for each watershed modeling segment were derived by converting the housing demand forecasts into estimates of future population. Future populations on sewer and septic were estimated by overlaying the SLEUTH probability map onto the modeled sewer service areas for 2030 to derive proportions of growth on sewer and septic which were then multiplied by the forecasted population in each modeling segment. The proportions of growth on sewer and septic were kept constant for all interim year forecasts between 2000 and 2030. The percent change in population within each sewer service area was used to estimate the percent change in flow for all wastewater treatment plants within and/or close to each service area.

State and Local Reviews

Following state and local government review of the trend forecast, outreach to state and local governments will continue through December 2009 to develop alternative future scenarios. Such scenarios can be developed based on local and regional land use plans and/or proposed policies, plausible assumptions about future drivers and/or patterns of change, or by adjusting model assumptions and input variables to bound the trend forecast.